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Effect of partial shading in grid connected solar PV system with FL Controller

K. Latha Shenoy[1,3], C. Gurudas Nayak[2], Rajashekar P Mandi[3]
[1]Department of Electrical and Electronics Engineering, NMAM Institute of Technology, Nitte
[2]Department of Instrumentation & Control Engineering, MIT, MAHE, Manipal
[3]School of Electrical & Electronics Engineering, REVA University, Bangalore

Article Info

ABSTRACT

As conventional fossil fuel reserves shrink and the danger of climate change prevailing, the need for alternative energy sources is unparalleled. A smart approach to compensate the dependence on electricity generated by burning fossil fuels is through the power generation using grid connected PV system. Partial Shading on PV array affects the quantity of the output power in photovoltaic (PV) systems. To extract maximum power from PV under variable irradiance, variable temperature and partial shading condition, various MPPT algorithms are used. Incremental conductance and fuzzy based MPPT techniques are used for maximum power extraction from PV array. Basically 11 kW Solar PV system comprising of PV array coupled with an Inverter through a dc-dc converter is considered for the analysis and output of the inverter is supplied to the load through the LCL filter. An Intelligent controller for maximum power point tracking of PV power is designed. Also, a fuzzy controller for VSC is developed to improve the system performance. The above proposed design has been simulated in the Matlab Simulink and analyzed the system performance under various operating conditions. Finally, the performance is evaluated with IEEE 1547 standard for showing the effectiveness of the system.

Corresponding Author:

K. Latha Shenoy
Departement of Electrical and Electronics Engineering
NMAM Institute of Technology
Nitte, Udupi District, Karnataka, India
Email: lathashenoy@nitte.edu.in

1. INTRODUCTION

Major global issues namely World Energy Crisis and Human Induced Climate change or global warming caused due conventional power generation, resulted in swing towards power extraction from renewable energy sources such as photovoltaic (PV) and wind generation systems, thereby replacing conventional power generation units. In India, the average annual solar energy incident on land area alone is about 5000 trillion kilowatt-hours because India gets about 300 clear sunny days in a year. The solar energy output received in a year exceeds the possible energy output of all the fossil fuel reserves in India [1]. Though solar energy is available free and abundantly in nature to meet the energy requirement, extracting it requires solar module whose initial investment cost is very high. Also, the efficiency of PV cell is low between 6-20%. The monocrystalline PV cell has highest efficiency between 14-20% [2]. Hence the maximum power point tracking algorithm is playing a very essential role in renewable energy sources for generating maximum power at various weather conditions. The solar photovoltaic system generates electricity when sunlight falls on modules. The sunlight irradiance is nonlinear in nature and varies time to

time due to which PV modules unable to generate maximum power [3]. To extract the energy present in these renewable sources state-of-art power electronic systems are essential [4]. The PV system may perform power conversion in single stage or double stage of control operation. For single stage power conversion, inverter controller itself incorporate control of both MPPT and grid voltage. In the double stage conversion, a dc/dc converter used in the first stage and dc/ac inverter is connected in the second stage. The maximum power point tracking is done using the dc/dc converter whereas dc/ac inverter is used to produce the appropriate reference dc voltage for dc to ac conversion [5]. The inverter will convert DC voltage into three-phase sinusoidal voltages or currents which is then delivered to the grid in a grid-connected solar PV system or to the load in a stand-alone system [6]. The unpredictable and fluctuating nature of resource is major concerns of solar energy systems. Hence to overcome this issue, grid-connected renewable energy systems are accompanied by battery energy storage [7]. This paper is concerned with the design and study of a grid-connected three-phase solar PV system especially under partially shaded condition of PV arrays.

The total installed capacity of photovoltaic is over 30 GW in 2019, including both ground mounted and roof top solar system according to the "State wise installed solar power capacity" reports of Ministry of New and Renewable Energy, Govt. of India [8]. Shading can result in a large reduction in power output. Cells in modules are normally connected in series, so when one or several cells are shaded, the current output of the module will be reduced. If the module is part of an array, then the current output of the array will also be reduced [9]. Shading of the array can lead to irreversible damage. However, bypass diodes can be used to mitigate temporary shading. The combination of different distributed generation units and local loads forms a small self-sustaining power network which serves its local load. Generally, it can be operated in grid connected mode or grid isolated mode [10], [11]. Various controllers like PI controller, fuzzy controller is used for grid integration. The fuzzy controller will improve the system performance in case of grid connected PV system [12], [13]. This will result in lower cost, better efficiency and increased flexibility of power flow control. The lay out of the paper is organized as follows. Section II describes the Fuzzy based MPPT controller for PV system in order to track the maximum power output from the PV panel and fuzzy controller for VSC controller. Section III presents the proposed topology to integrate solar PV with the grid and its associated control system. Section IV describes the experimental results and analysis of the performance of the proposed system. Section V includes the conclusion of the paper.

2. MPPT CONTROLLER FOR PV SYSTEM

To extract maximum power from PV, the output resistance needs to be equal to the input resistance. To obtain sufficient input resistance, the duty cycle of the converter switch is required to adjust. The maximum power point tracking (MPPT) algorithm plays a very essential role in renewable energy sources for generating maximum power under various weather conditions. One of the most common MPPT techniques is the Hill Climbing or perturb and observe (P&O) method. The conventional algorithms such perturb and observe (P&O), incremental conductance (IC) used have limitations. To overcome this, soft computing method such as Fuzzy Logic, Neural Networks, Artificial Intelligence, Particle Swarm Optimization, are also proposed for solving the MPPT problem [14], [15]. In this paper, the fuzzy logic controller based MPPT algorithm has been developed and simulated in Matlab environment [16]. The overall structure of the proposed grid connected PV system is shown in Figure 1. Two fuzzy controllers are developed for the converters. The boost converter-based PV MPPT system has been developed in Matlab as shown in Figure 2. The specification about the module used for PV system is shown in Table 1.
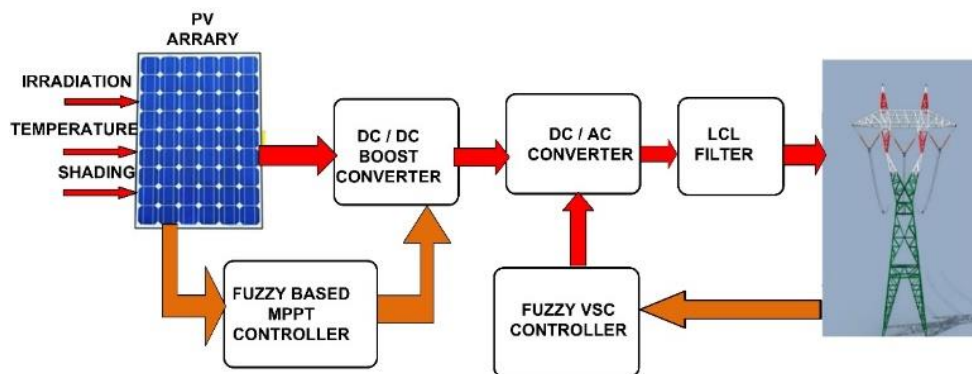

Figure 1. Block diagram of proposed grid connected PV System

Table 1. Solar PV module specifications

SL No	Parameters	Ratings
1	Maximum power Pmp	200 W
2	O.C voltage	30.8 V
3	Voltage at maximum power point	24.5 V
4	Current at maximum power point	8.16 A
5	Parallel strings	6 nos
6	Series connections per string	9 nos

2.1. Design of fuzzy logic controller

The fuzzy logic controller has been developed with two inputs and one output functions such as PV voltage, PV current and duty cycle of the PV boost converter as shown in Figure 2. The fuzzy PV voltage input membership function is classified three ranges such as low voltage (LV), medium voltage (MV) and high voltage (HV) [17]-[20]. The fuzzy PV current input membership function is classified three ranges such as low current (LI), medium current (MI) and high current (HI). The fuzzy duty cycle output membership function is classified three ranges such as low duty cycle (LD) medium duty cycle (MD) and high duty cycle (HD). The mamdani based fuzzy controller is used for PV MPPT as shown in Figure 3(a).
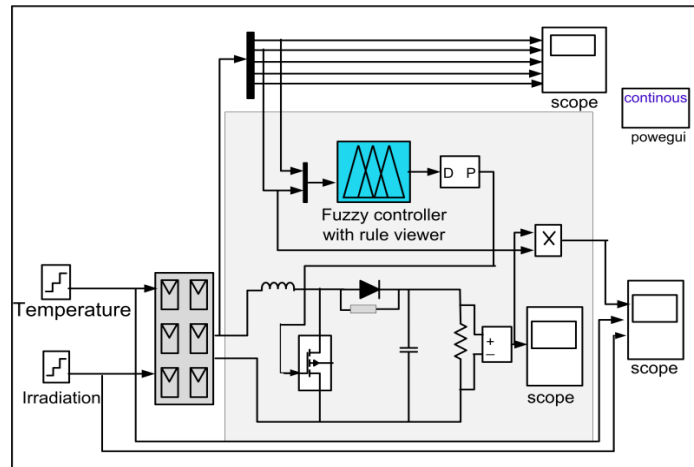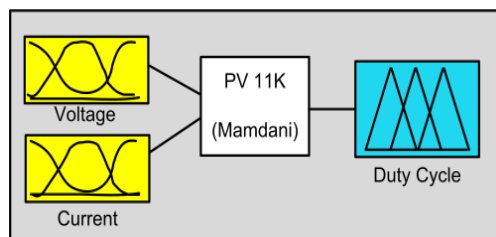

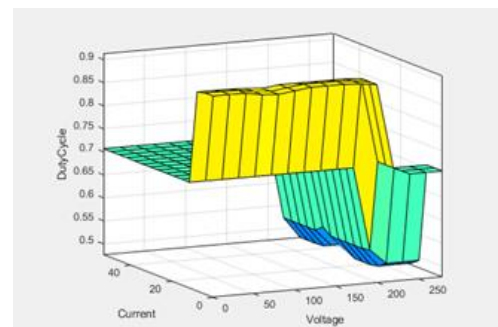Figure 2. Fuzzy based MPPT controller simulation model of grid tie PV system

The fuzzy rule basis obtained as shown in Table 2. Figure 3(b) indicates the surface view of fuzzy MPPT controller.

Table 2. PV MPPT fuzzy rules basis

Fuzzy membership	LI	MI	HI
LV	HD	HD	HD
MV	HD	MD	MD
HV	MD	MD	LD

(a)	(b)

Figure 3. (a) Fuzzy based MPPT controller; (b) fuzzy rules surface system for MPPT controller

The PV arrary performance under different irradiation and temperature is taken for the analysis. The Figure 4(a) shows the current versus voltage characteristic of the PV arrary for temperatures of 25°C, 45°C, 55°C and 75°C. It is observed that as temperature increases the open circuit voltage decreases whereas the short circuit current increases by small fraction. Figure 4(b) indicates the variation of power versus the arrary voltage under different temperature like 25°C, 45°C, 55°C and 75°C. It is observed from the curve that power output from the panel decreses as the temperature of the PV panel increases. Hence it is essential to provide cooling for the panel inorder to obtain the desired output from the PV array.
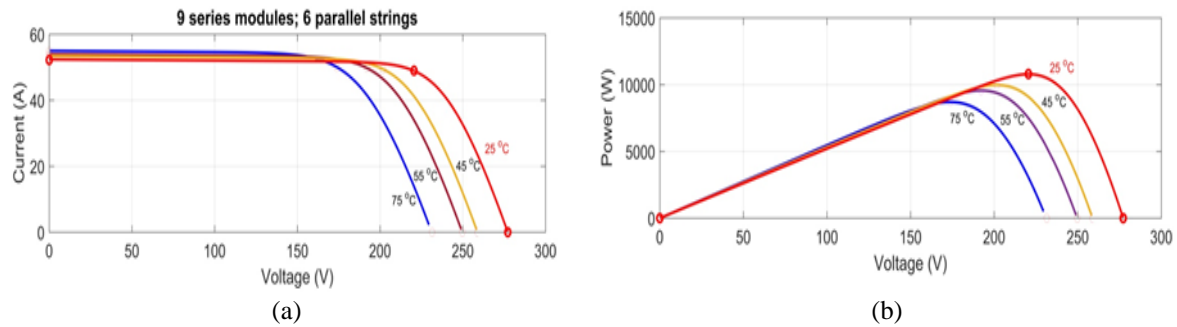

Figure 4. Solar PV array characteristics under variable temperature condition (a) current versus voltage, (b) power versus voltage (P-V)

Figure 5(a) indicats the current versus voltage characteristic of the PV array under irradiation of 100 W/m^2, 500 W/m^2, 750 W/m^2, 1000 W/m^2. The current produced by the PV cell decreses as the irradiation decreases. The PV generated current is 50 A for the irrdation of 1000 W/m^2. The Figure 5(b) indicates power versus voltage characteristic. As the irradiation received by the PV decreses, the yield of the PV array decreases. It produces power output of 11 KW for the irradiation of 1000 W/m^2.
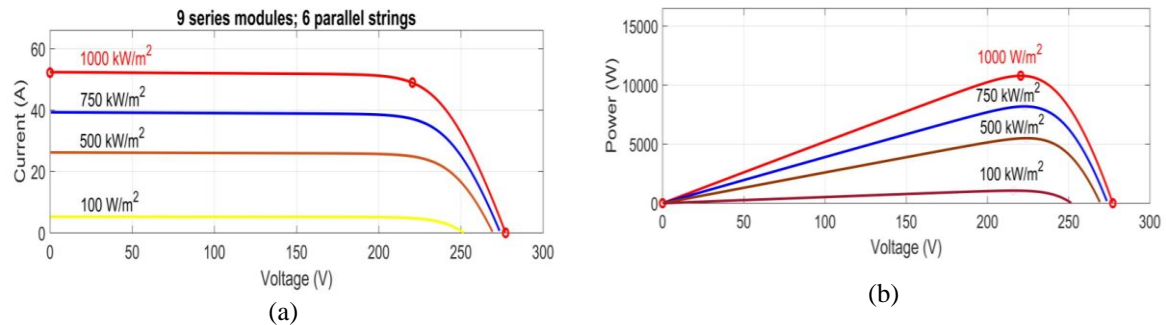

Figure 5. PV array characteristics under variable irradiance (a) I-V characteristics (b) P-V characteristics

2.2. Design of Fuzzy Controller for VSC

The current regulator for voltage source converter is developed using fuzzy logic controller with two inputs and two outputs functions. Input variables are referred as error values Id and Iq. The output variables are controlled Id and Iq. The error value of Id and Iq can be calculated by the difference between Id, Iq reference generated by voltage regulator and Id, Iq measured. The overall VSC controller structure is shown in Figure 6. The PLL block uses three phase voltage and current from the grid to generate the reference voltage required for the three-phase inverter [21]-[23].
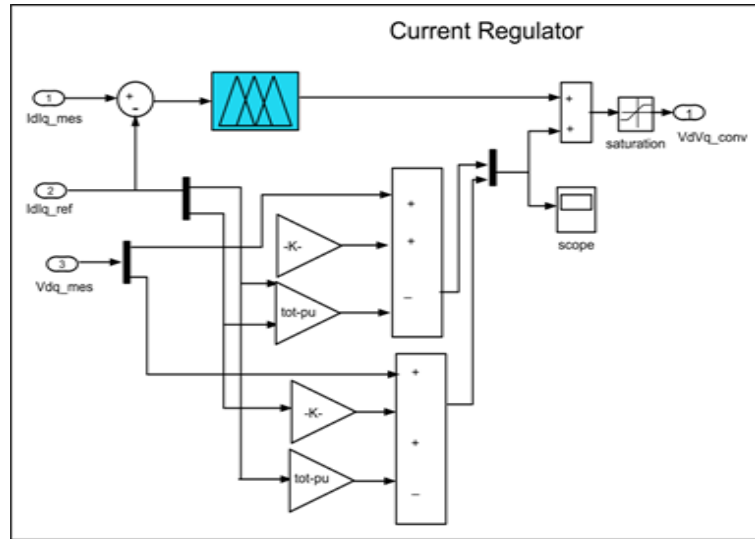
Figure 6. Fuzzy logic controllers for VSC

3. GRID CONNECTED PV UNDER PARTIAL SHADING CONDITION

The Figure 7 representes the simulation of PV system in matlab simulink carried out with fuzzy controllers. The proposed system consists of two PV arrays, each of 11 KW ratings is considered for the performance analysis of grid connected PV system. The array PV1 is receiving normal irradiation whereas another PV array (PV2) is under shaded condition. Whenever there is surplus PV generation, the excess power is delivered to the grid after meeting the load requirement. At the same time during evening if the PV generation is not sufficienct the grid supplies the deficit power to meet the load requirement. This power flow is represented in the Figures 8 and 9.
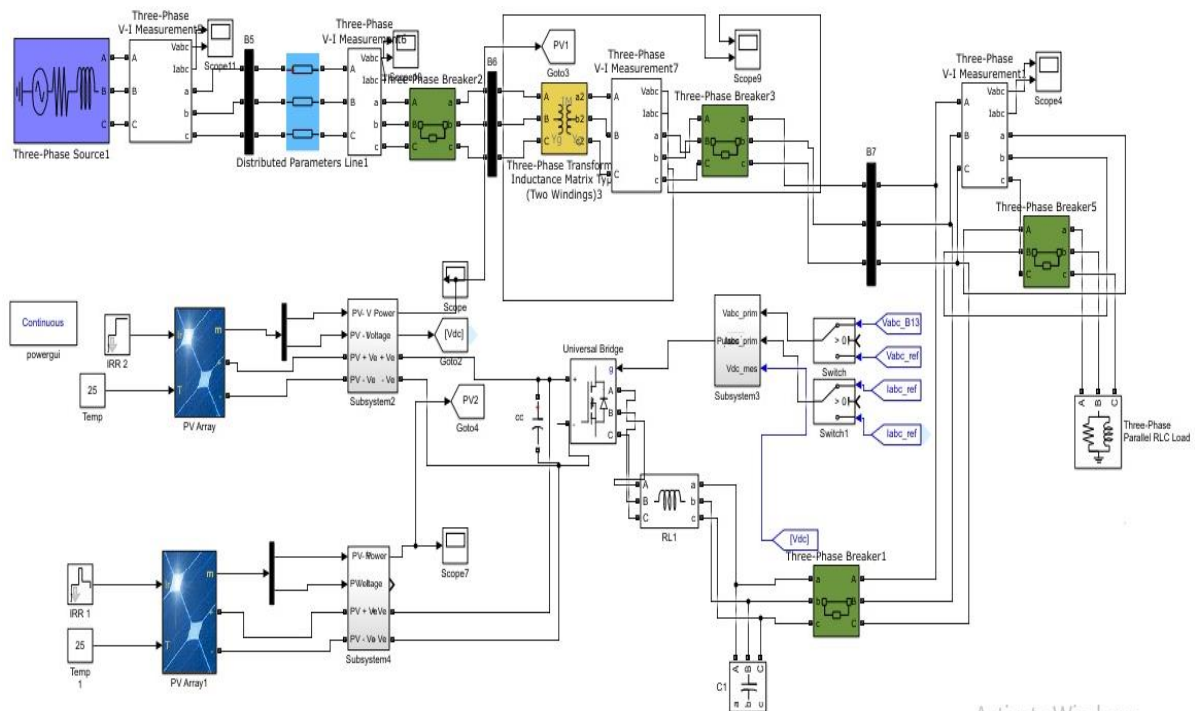

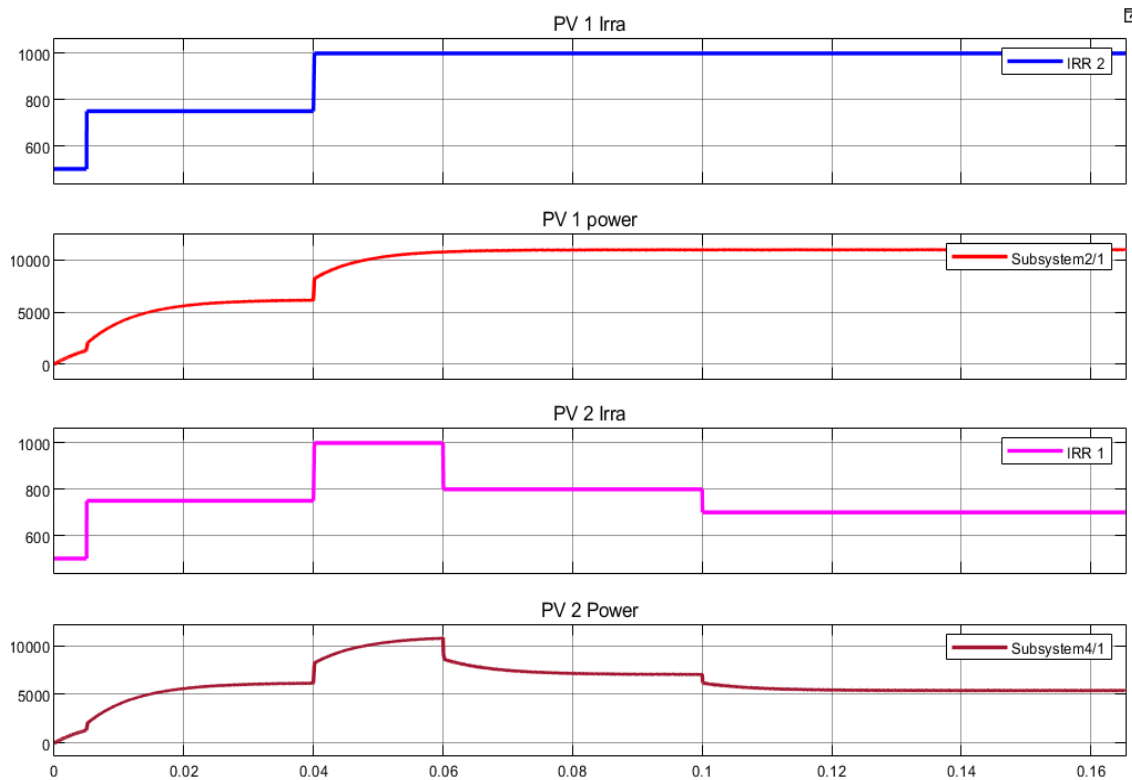Figure 7. Simulation diagram for PV system under partial shading

Figure 8. (a) Variation of irradiation for PV panel PV1, (b) total amount of power delivered by the panel PV1 for the corresponding irradiation, (c) variation of irradiation for PV panel PV2, (d) total power delivered under normal and partial shading condition by PV2
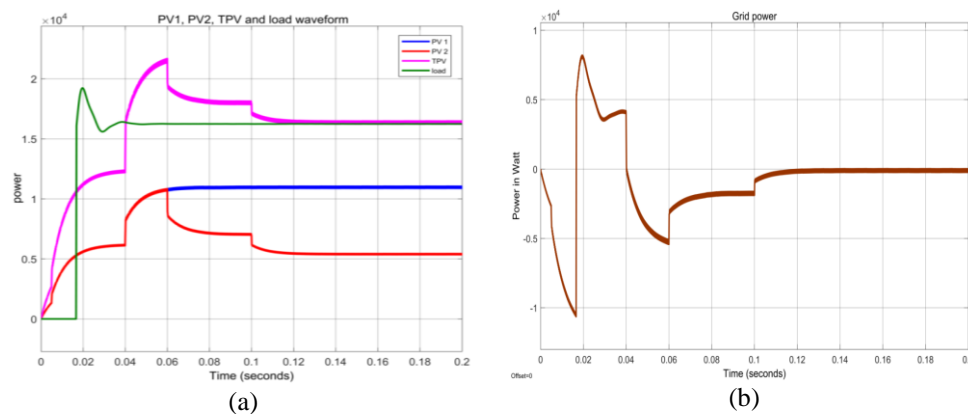

(a)

(b)

Figure 9. (a) Variation of PV under normal and shading conditions along with grid and load power requirement (blue line: PV 1 Power, Red line: PV 2 power, green line: load power and pink line: PV total power), and b) grid power variations for normal and partial shading condition

4. RESULTS AND ANALYSIS

At $t = 0$, both panel PV1 and PV 2 will be receiving irradiation of 500 W/m2 and hence able to generate power as represented in Figure 8. At $t = 0.004$ sec, PV1 and PV2 generates total power of 3 kW. Since no load is connected, the generated power will be delivered to the grid. It is shown with negative sign. At t= 0.005 sec, irradiation varies from 500 W/m^2 to 750 W/m^2. Hence total of 5000 W was generated by both the PV panels together. Since load is not connected to the system, the generated power of 5 kW was supplied to the grid. At t=0.015 sec, the power generation capacity of both the PV panels were around 10 kW. So total power of 10 kW was supplied to the grid. At $t = 0.03$ sec, load of around 16 kW is applied to

the system. Now the generation is 12 kW was obtained for the given irradiation. In order to meet the load demand, there is deficit of 4 kW power which will be drawn from the grid. At $t = 0.04\ sec$, further irradiation increases to 1000 W/m², generating the power of 8 kW each. Hence total power generated by the PV panel is 16 kW. Under this condition no power is delivered to the gird, as generation and demand both are equal. At $t = 0.05\ sec$, total power generation is 20 kW. The additional excess power of 4000 W was then fed to the grid. At $t = 0.06\ sec$, the solar panel PV2 was under partial shading effect. It receives irradiation of 800 W/m². Under this partial shading condition, it generates reduced power of 8000 W. Therefore, total power 19 kW is generated. Hence excess power 3 kW is delivered back to the grid. It will continue till 0.1 sec at which further irradiation on PV2 falls to 700 W/m² due to partial shading. The total generated power now is 18 kW. The excess power of 2 kW is sent to the grid [24]-[26]. Table 3 gives the details of PV power generated by both panels for different irradiation. Also, it gives the details about the power flow between load and the grid.

Table 3. Power distribution among PV, Grid and load for different irradiation

Power	0.004Sec	0.005Sec	0.015Sec	0.03Sec	0.04Sec	0.05Sec	0.06 Sec	0.1Sec
PV1 Irradiation	500 W /m²	750W /m²	750W/m²	750W/m²	1000W/m²	1000W/m²	1000W/m²	1000W/m²
PV1 Power	1500 W	2500 W	5000 W	6000 W	8000 W	10000 W	11000 W	11000 W
PV2 Irradiation	500W/m²	750W/m²	750W/m²	750W/m²	1000W/m²	1000W/m²	800W/m²	700W/m²
PV2 power	1500 W	2500 W	5000 W	6000 W	8000 W	10000 W	8000 W	7000 W
Total PV Power	3000 W	5000 W	10000 W	12000W	16000 W	20000 W	19000 W	18000 W
Load Power	0 W	0 W	0 W	16000W	16000 W	16000 W	16000 W	16000 W
Grid Power	-3000 W	-5000 W	-10000 W	+ 4000W	0 W	-4000 W	- 3000 W	-2000 W

Figure 9(a) indicates the variations in power delivered by PV panels, PV1 and PV2 under normal and partial shading conditions. The load of 16 kW is applied at time $t = 0.016$ sec. The Figure 9(b) shows the corresponding variation in the grid power during various time intervals. During the period 0.04 to 0.1 sec, the PV generation is less than the demand. Hence grid supports the additional load. For the analysis of power flow, sign convention for grid power is taken as represented below. Positive sign indicates power is supplied by the grid to meet the load demand. Negative sign indicates excess generated power is given back to the grid. The Table 4 shows the comparison between various controllers used for the PV system.

Table 4. Comparative table

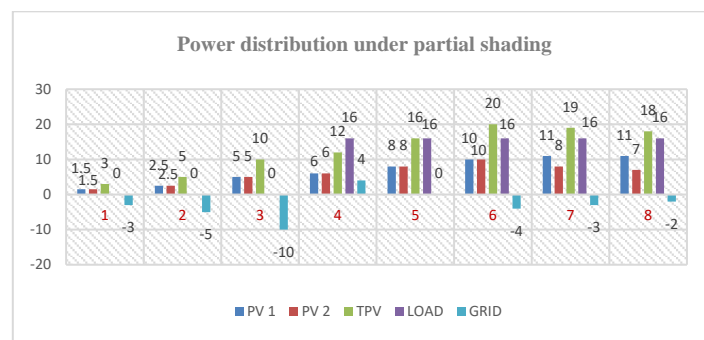| Profile	Total Harmonic Distortion (THD)	
	PI	Fuzzy
Voltage	2.39 %	1.28%
Current	13.6 %	4.79%

Figure 10. Bar chart of power exchange between PV, load and grid
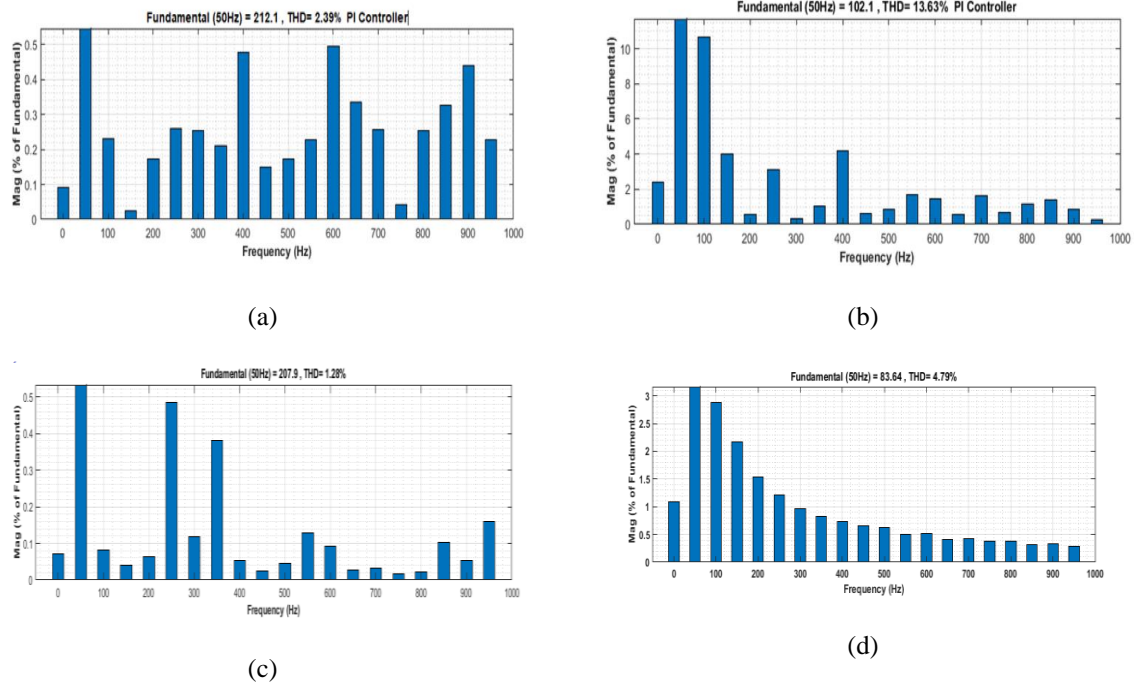
(a)

(b)

(c)

(d)

Figure 11. (a) Voltage THD waveform with PI controller, (b) current THD waveform with PI controller,
(c) voltage THD waveform with fuzzy controller, (d) current THD waveform with fuzzy controller.

5.   CONCLUSION

This paper deals with the modeling of solar PV system under variable irradiance, variable temperature and partial shading condition of the array. The performance analysis of the PV system under partial shading condition for grid connected PV system is done. The fuzzy controller has been developed for maximum power point tracking for 11 kW photovoltaic power systems under partial shaded condition. Its performance under load condition is verified. The proposed PV system for grid integration has been simulated in matlab simulink and a fuzzy controller for grid synchronizing of PV system into the power grid is developed. Finally, the proposed model simulation results are analyzed with different operating conditions and evaluated with IEEE 1547 standard for proving the effectiveness system. In PI controller-based systems, the total harmonic distortion values for load voltage and current are measured and presented in Figures 11(a) and 11(b) respectively. The THD values of voltage and current for the fuzzy based system are 1.28 % and 4.79 % as represented in the Figures 11(c) and (d) respectively. Based on the standard value for grid integration of renewable energy sources, THD values less than 5 % is acceptable. The load voltage and current waveforms are sinusoidal.

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BIOGRAPHIES OF AUTHORS

K. Latha Shenoy is presently working as assistant professor, Department of Electrical & Electronics engineering, NMAM Institute of Technology, Nitte. She received her B.E. degree in Electrical & Electronics Engineering from Mangalore University in 1996. She has 15 years of teaching experience and 4 years of industrial experience. She has published more than 16 technical papers in National, International Conferences and Journals. She received M. Tech degree in digital Electronics and Advanced communication from Manipal Institue of Technology, Manipal. Her research interests include renewable energy systems, power electronics, control systems.

Dr. C Gurudas Nayak received his B.E. in Instrumentation Technology in 1988 from Gulbarga University, Gulbarga India and M.S.in Communication Engineering in the year 1996 from NewPort University, USA and PhD from MAHE, Manipal India in the year 2008. He has 30 years of Industrial /teaching experiences and published 100 papers in International, National Conferences and journals. He is currently working as a Professor in the Instrumentation and Control Engineering Department, Manipal Institute of technology, Manipal University, Manipal. His research interests include of Communication Networks, Instrumentation and Transducers and Mobile Telephone Systems.

Dr. Rajashekar P. Mandi is presently working as Director of School of Electrical Engineering, REVA University, Bangalore. Before joining REVA University, he worked in Central Power Research Institute, Bangalore for more than 26 years in research. He received M. Tech. degree in Energy Systems Engineering from Visweswaraiah Technological University, Belgaum with 3rd rank and Ph. D in Power and Energy from NITK, Surathkal through research. He is a professional member of IEEE. He is accredited energy auditor from Bureau of Energy Efficiency (BEE), Govt. of India. He is presently chairman of Society for Energy Efficiency & Manager (SEEM) Karnataka Chapter.